PROKARYOTES

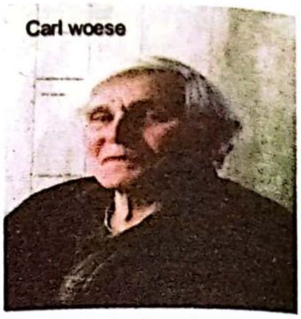
Chapter 6

Major Concept

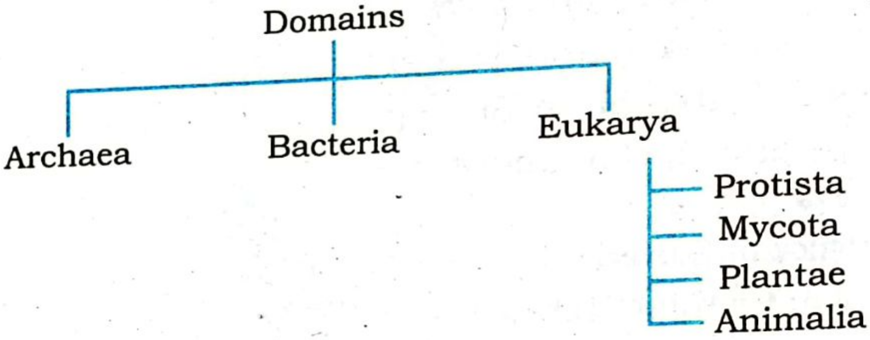
In this Unit you will learn:

- Taxonomy of Prokaryotes
- Archaea
- Bacteria; Ecology and Diversity
- Structure; Shape and Size of Bacteria
- Modes of Nutrition in Bacteria
- Growth and Reproduction in Bacteria
- Importance of Bacteria
- Control of Harmful Bacteria

6.1 TAXONOMY OF PROKARYOTES



In recent past all living organisms are grouped into five kingdoms and Prokaryotes were placed into the kingdom Monera (Prokaryotae) but now the status of classification has been changed in late 90's. The pioneer work had been conducted by Carl Woese (1990) and his colleagues proposed domain system of classification based upon the differences of subcellular structure ribosomes and cell membranes. He described that life has evolved on earth along three lineages called domain which include Bacteria, Archaebacteria (Archaea) and Eukaryotes (Eukarya). This division is widely accepted throughout the world.



In view of recent classification two out of three domains' Eubacteria and Archaebacteria are prokaryotes. The domain Eubacteria comprises all bacterial organisms and recently given status as kingdom bacteria, the domain Archaea comprises the rest of the prokaryotes, and the domain Eukarya includes all eukaryotes, including organisms in the kingdoms Protista, Fungi (Mycota), Plantae and Animalia.

Table 6.1.

Classification of organisms given by different scientist in different era

Linnaeus 1758	Haeckel 1866	Chatton 1925	Copeland 1938	Whittaker 1969	Woese et al. 1990
2 kingdoms	3 kingdoms	2 empires	4 kingdoms	5 kingdoms	3 domains
	Protista	Prokaryota	Monera	Monera	Bacteria
					Archaea
		Eukaryota	Protoctista	Protista	Eukarya
Plantae	Plantae		Plantae	Plantae	
				Fungi	
Animalia	Animalia		Animalia	Animalia	

6.1.1. Phylogeny of Prokaryotes

Prokaryotes are the most primitive and first inhabitant on earth. Earth at that time highly exposed to radiations and probably had a very less molecular oxygen therefore prokaryotes were adapted to those conditions. The prokaryotes may have evolved from protobionts ancestors. Their early selective habitat could be the microbial mats as evidenced by the fossil presence aged 3.5 billion years ago. These mats are few centimeters thick, moist and sticky due to the secretion of extracellular matrix from Prokaryotes and found near hydrothermal vents to obtain energy and food from these vents. These mats when dried becomes stromatolite as a sedimentary structure represents the earliest fossilized record of life on earth.

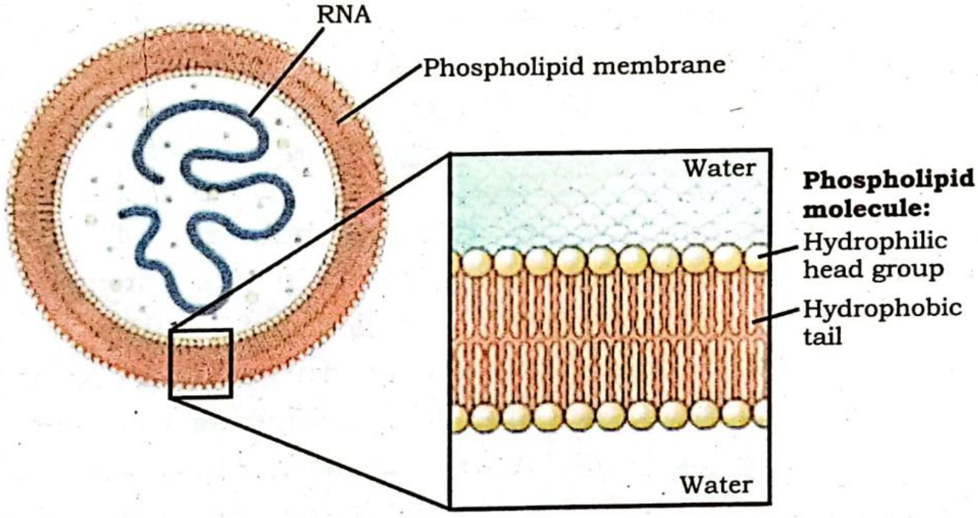


Fig. 6.1. Protobiont:
Enclosure of self-replicating RNA in a phospholipid membrane. The first cell is thought to have arisen by the enclosure of self-replicating RNA and associated molecules in a membrane composed of phospholipids.

Prokaryotes present in every habitat and each comprised of several smaller taxonomic groups. The domain Bacteria of the Prokaryote also include cyanobacteria or blue-green algae. This primitive prokaryotic alga can perform photosynthesis and are called photoautotrophs. Higher phototrophic autotrophs are thought to have evolved from this group. They have well developed pigment system and can reproduce by fragmentation. Bacteria also exist as decomposers or saprotroptus and symbionts.
Prokaryotes have tremendous ability to adapt according to the changing environment. Their genome has much role in developing this ability extending up to genetic level for example bacterial species *Escherichia coli* contains approximately 5,000 genes. On average, about one in every 200 bacteria is likely to have a mutation in at least one of the genes.

6.2. DOMAIN ARCHAEA

Archaea is a very diverse group in a domain system of classification. They were initially classified as Archaebacteria but this classification is obsolete now they are a separate domain. They are present in different shapes like spherical, rod, lobed, square etc. their diameter ranging 0.1 to over 15μm. Archaea are slightly different from bacteria. They don't have peptidoglycan in their cell wall as it is present in bacteria and also some metabolic activities are different from bacteria. Archea reproduce asexually by binary fission, fragmentation or budding.

> Curd may contain a wide variety of bacteria like *Lactobacillus acidophilus, Lactococcus lactis,* etc., whereas yogurt contains *Streptococcus thermophilus* and *Lactobacillus bulgaricus*. Anaerobic bacteria in the oral cavity include:, *Eubacterium*, *Lactobacillus*, *Selenomonas*, *Treponema*, *etc*.

Archaea can live in different habitats of extreme condition and classified accordingly like those living in hot springs called thermophiles, high acidic conditions dwellers called acidophiles and methanogens are found in marshy areas and in gut produces biogas to obtain energy another group includes halophiles that live in high salt concentration environment as they require high salt for their growth. Although they are almost similar with bacteria in shape and size but genetically, they also have some affinity with eukaryotes like they have genes that produce enzymes particularly polymerase used in metabolic activities during translation and transcription as present in eukaryotic organisms. Archeal membrane composition is bit different from bacterial membranes marking as unique character. They have hydrocarbons attached to glycerol by ether linkage rather than ester linkages this combination is also called **archaeol** specially in methanogens while in bacterial membrane glycerol ester lipids are presents. *Example Methanococcus, Halobacterium*

They do not live as pathogens or parasites instead they develop useful associations with others as mutualists or commensals for example methanogen archea *E.coli* live in human intestine and helps in digestions, marine archean *Cenarcheaum symbiosum* lives within sponge *Axinella mexicana* as symbiont, some thermophile archea used in biotechnology due to their endurance of high temperature.

Table 6.2. Comparison of domain system classification

Characteristics	DOMAINS		
	Archaea	Bacteria	Eukarya
Cell Membrane	Ether-linked lipids, pseudopeptidoglycan	Ester-linked peptidoglycan	Ester linked lipids, various structures
Gene Structure	Circular chromosomes, similar translation and transcription to Eukarya	Circular chromosomes, unique translation and transcription	Multiple, linear chromosomes, similar translation and transcription to Archaea
Internal cell structure	No membrane-bound organelles or nucleus	No membrane-bound organelles or nucleus	Membrane-bound organelles and nucleus
Metabolism	Various methanogenesis unique to archaea	Various, including Photosynthesis, aerobic and anaerobic respiration, fermentation, and autotrophy	Photosynthesis and cellular respiration
Reproduction	Asexual reproduction, horizontal gene transfer	Asexual reproduction, horizontal gene transfer	Sexual and asexual reproduction

6.3. BACTERIA ECOLOGY AND DIVERSITY

Earth is formed around 4.5 billion years ago. The evolution of this planet and its atmosphere gave rise to life, which shaped earth's subsequent development. When earth was evolved the allover environmental conditions are not so good for any living organism. Initial temperature is very high the volcanic activities releasing gasses probably created the atmosphere and the oxygen almost unavailable. The earliest undisputed evidence of life on earth dates at least from 3.5 billion years ago. Since then, life has evolved into a wide variety of forms. As evolution proceeds fossil records indicate bacterial colonization developed and acquired different areas of earth. Later on, some started making their own food using carbon dioxide from the atmosphere and energy they harvested from the sun. These initial photosynthetic organisms helped establish a stable atmosphere and produced oxygen in such quantities that eventually life forms could evolve that needed oxygen. Soon afterward, new oxygen-breathing life forms came onto the existence.

With a population of increasingly diverse bacterial life, the stage was set for more life to form. There is compelling evidence that mitochondria and chloroplasts were once primitive bacterial cells. The Russian botanist Konstantin Mereschkowski first outlined the **theory of symbiogenesis** (Endosymbiotic) which states that some of the organelles in today's eukaryotic cells were once prokaryotic microbes. Over millions of years of evolution, mitochondria and chloroplasts have become more specialized and today they cannot live outside the cell. Mitochondria and chloroplasts have striking similarities to bacteria cells. They have their own DNA, which is separate from the DNA found in the nucleus of the cell and both organelles use their DNA to produce many proteins and enzymes required for their function. A double membrane bounding both mitochondria and chloroplasts is further evidence that each was ingested by a primitive host. The two organelles also reproduce like bacteria, replicating their own DNA and directing their own division.

> Mitochondrial DNA (mtDNA) has a unique pattern of inheritance. It is passed down directly from mother to child, and it accumulates changes much more slowly than other types of DNA. Because of its unique characteristics, mtDNA has provided important clues about evolutionary history. For example, differences in mtDNA are examined to estimate how closely related one species is to another.

6.3.1. Bacterial habitat

Bacteria can be found in almost all the habitat on earth. They are present in soil, water, plants, animals, radioactive waste, deep in the earth's crust, arctic ice and glaciers and in hot springs. Their range extending up to 30 miles up in the atmosphere and 10,000 meters deep in water. A gram of soil typically contains about 40 million bacterial cells. A milliliter of fresh water usually holds about one million bacterial cells. The earth is estimated to hold at least 5 nonillion bacteria, and much of the earth's biomass is thought to be made up of bacteria. This distribution also ensures the evidence that bacterial colonization and endurance develops due to the extreme environment when the earth is formed. Deep in the ocean environment is total dark and both temperature and pressure are very high, bacteria living in these areas survive by oxidizing … deep inside the earth.

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Table No. 6.3
Types of bacteria on the basis of mode of respiration

Aerobic bacteria	Anaerobic bacteria
Live in places where oxygen is available	Live in places where oxygen is not available
They produce CO_2 and H_2O	They produce CO_2, ethanol and Lactic acid
Live in soil, water and open surfaces	Live in areas where oxygen is depleted like intestine, marshes
Produce more energy Example *Lactobacillus, Mycobacterium*	Produce less energy Example *Clostridium and E. coli*

Like Archea different bacteria also live in different extreme environment.

6.3.2. Major groups of bacteria

Carl Woese studied the differences in rRNA sequences in different organisms and established the evolutionary relationships among species. On that basis domain bacteria classified into five major phylums namely Proteobacteria, Chlamydias (Gram-negative), Spirochetes, Cyanobacteria, and gram-positive bacteria.

Table 6.4 Different groups of bacteria

	Phylum	Characters	Example
Domain Bacteria	**Protobacteria**	Free living and symbionts Some are pathogenic	*Helicobacter pylori* causes stomach ulcer *Salmonella* causes food poisoning
	Chlamydias (Gram-Negative bacteria)	Obligate intercellular parasite Cell wall with low peptidoglycan	Chlamydia trachomatis causes sexually transmitted disease
	Spirochetes	Spiral shaped, free living anaerobes Pathogenic Flagella present	*Treponema pallidum* causes Syphilis
	Cyanobacteria	Known as blue green algae Chlorophyll present Present in aquatic environment	*Prochlorococcus* most abundant photosynthetic organism on earth
	Gram-Positive bacteria	Pathogenic and decomposers Thick cell wall and without outer membrane	*Clostridium botulinum* cause botulism *Bacillus anthrax* cause anthrax

6.3.3. Cyanobacteria as photosynthetic bacteria

Cyanobacteria is the most prominent primitive photosynthetic organism that earth acquired in its wide range of habitats. They have remarkable ability to survive in extremely high and low temperatures. Primarily these are found in aquatic environment and established around 2.5 billion years ago. At that time when earth was suffering from high temperature and oxygen deficiency, they were contributed in providing oxygen to our atmosphere by using water during photosynthesis and using CO_2 might had reduced the earth temperature to some extent. Their life processes require only water, CO_2, inorganic substances and light. Their abilities to colonize on rock and soil, in tough environmental conditions like glaciers and near volcanos and radiation.

Cyanobacteria can survive in low CO_2 environment. They have RuBISCO enzyme that help to convert CO_2 into sugars. Filamentous cyanobacteria can fix elemental nitrogen in their specialized cells called **Heterocyst** and they are used in fertilizers as produced by *Nostoc*. Some of the cyanobacteria also produce toxic substances which contaminate water and if drink commonly cause gastroenteritis.

Cyanobacteria don't have chloroplast for being the most primitive form but the green pigments are present. Since they are the primitive one and do not represent the true photosynthetic eukaryotic cellular organization, therefore they require little amount of energy to maintain cellular activities and have the higher growth rate than other phytoplanktons when light intensities are low. They can also live within the organisms for developing mutualism and also can live. They have chlorophyll a, carotenoids and the blue pigment phycobilin while in some species, the red pigment phycoerythrin is also present. If they have not evolved on earth, it would have low level of oxygen all around and most of the life form could not been able to exists.

6.4. STRUCTURE OF BACTERIA

Bacteria are the prokaryotic unicellular organisms. Structurally bacterial cell has three distinct regions first appendages that include **flagella** and **pili** which helps bacteria cell in locomotion and floating respectively, secondly cell coverings consisting of **capsule** the outermost covering in some cells, cell wall and cell membrane and third is cytoplasmic region that contains the cell chromosome (DNA), **plasmid** as the extra circular molecule of DNA used

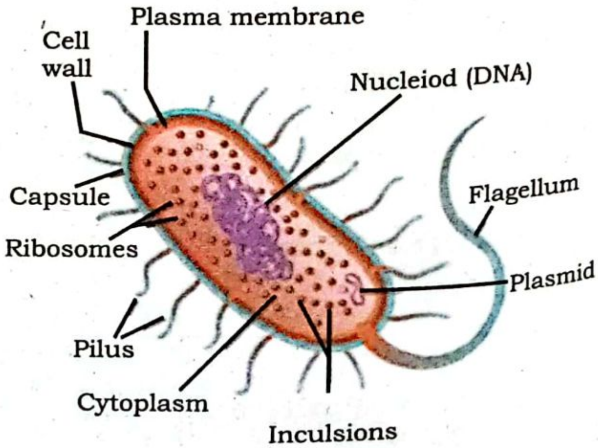


Fig. 6.2 Bacterial structure

in conjugation and also protect bacteria from antibiotics. Bacteria also contain **Ribosomes** for protein synthesis, **Mesosomes** the membranous invaginations which helps in DNA replication, cell division respiration and export of enzymes and various inclusions. Inclusions are considered to be nonliving components of the cell that do not perform metabolic activities and are not bounded by membranes. The most common inclusions are glycogen, lipid droplets, crystals, and pigments.

Generally bacterial cells have two protective coverings the outer **cell wall** and inner **cell membrane**. Some bacteria have a third outermost protective covering called **glycocalyx** which separates bacterial cell from its surroundings. Glycocalyx may be condensed to form **capsule** and **slime** which is soft and sticky according to the surrounding environment. Capsule form of glycocalyx relatively tightly associated with cell wall, it provides sticky or gummy nature to the cell wall, where as slime is loosely attached with cell wall and gives slimy and slippery nature to bacterial cell. which is formed by polysaccharide, polypeptide and hyaluronic acid in different species. Mostly capsules are hydrophilic and protect bacteria from desiccation. Capsule protects bacteria from ingestion of WBCs and increases the bacterial pathogenicity in host organisms. Another function of glycocalyx is to promote adhesion with each other and form biofilm, biofilm bonding become more resistant and harder to kill.

Table 6.5.
showing Cell wall differences in Gram-positive and Gram-negative bacterial cell wall.

S.N.	Character	Gram-Positive Bacteria	Gram-Negative Bacteria
1.	Gram Reaction	Retain crystal violet dye and stain blue or purple on Gram's staining.	Accept safranin after decolorization and stain pink or red on Gram's staining.
2.	Cell wall thickness	Thick (20-80 nm)	Thin (8-10 nm)
3.	Peptidoglycan Layer	Thick (multilayered)	Thin (single-layered)
4.	Rigidity and Elasticity	Rigid and less elastic	Less rigid and more elastic
5.	Outer Membrane	Absent	Present
6.	Variety of amino acid in cell wall	Few	Several
7.	Aromatic and Sulfur-containing amino acid in cell wall	Absent	Present

8.	Teichoic Acids	Mostly present	Absent
9.	Lipid and Lipoprotein Content	Low (acid-fast bacteria have lipids linked to peptidoglycan)	High (because of presence of outer membrane
10.	Cell Wall Disruption by Lysozyme	High	Low (requires pretreatment to destabilize outer membrane)
	Examples	*Staphylococcus* *Streptococcus* *Bacillus* *Clostridium* *Enterococcus*	*Escherichia* *Salmonella* *Klebsiella* *Proteus* *Helicobacter* *Pseudomonas*

Bacterial cell wall

The bacterial cell wall is made up of **murein,** which is a mixture of two conjugated molecules called lipoglycan and peptidoglycan. It is specifically present only in prokaryotes cell wall and provides the cell shape and surrounds the cytoplasmic membrane to protect. Peptidoglycan is a conjugated structure contain polymer of disaccharides. From the peptidoglycan inwards all bacterial cells are very similar. The cell wall provides important ligands for adherence and receptor sites for viruses or antibiotics. On the basis of their cell wall structure and composition. Gram-positive bacteria, due to high content of peptidoglycan in their structure (as shown in the fig.6.8) retain crystal violet when stain while Gram negative bacteria due to less peptidoglycan and outer lipopolysaccharide content fail to retain stain and washed-out during alcohol treatment of staining process.

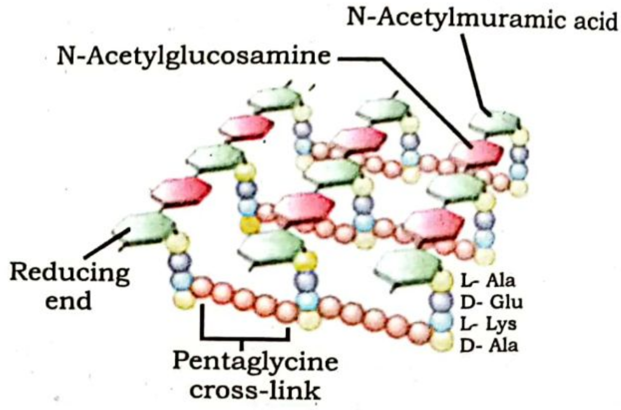


Fig. 6.3. Structure of Peptidoglycan in bacterial cell wall

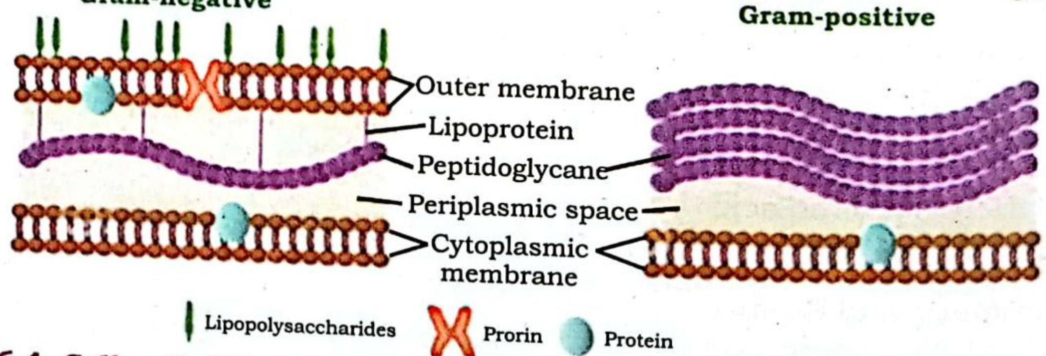


Fig. 6.4. Cell wall differences in Gram-positive and Gram-negative bacteria.

6.4.1. Shape and size of bacteria

Bacteria are found in different shapes and sizes. Bacteria are classified into five groups according to their basic shapes: spherical (cocci), rod (bacilli), spiral (spirilla), comma (vibrios) or corkscrew (spirochaetes).

1. **Cocci**: These are spherical and non-flagellated. **Cocci** exists in different arrangements like single cell, in pairs of two called **diplococci,** in groups of four called **tetrads**, in chains as **streptococci,** in clusters as **staphylococci** or in cubes consisting of eight cells as **sarcina**.
2. **Bacilli** are rod shaped maybe flagellated bacteria they exist in single form, paired form as **diplobacillus**, arranged in chains called **streptobacillus**, some are **coccobacillus** appears as short and stumpy ovoid and shaped in between coccus and bacillus. Few other are called **Palisades** long slender and their arrangement resembles with picket fence.
3. **Spirilla** (or spirillum for a single cell) are flagellated deeply curved from the middle of the body.
4. **Vibrio** are slightly curved bacteria like comma shape with flagella.
5. **Spirochetes** are long, slender, and flexible cork screw like bacteria.

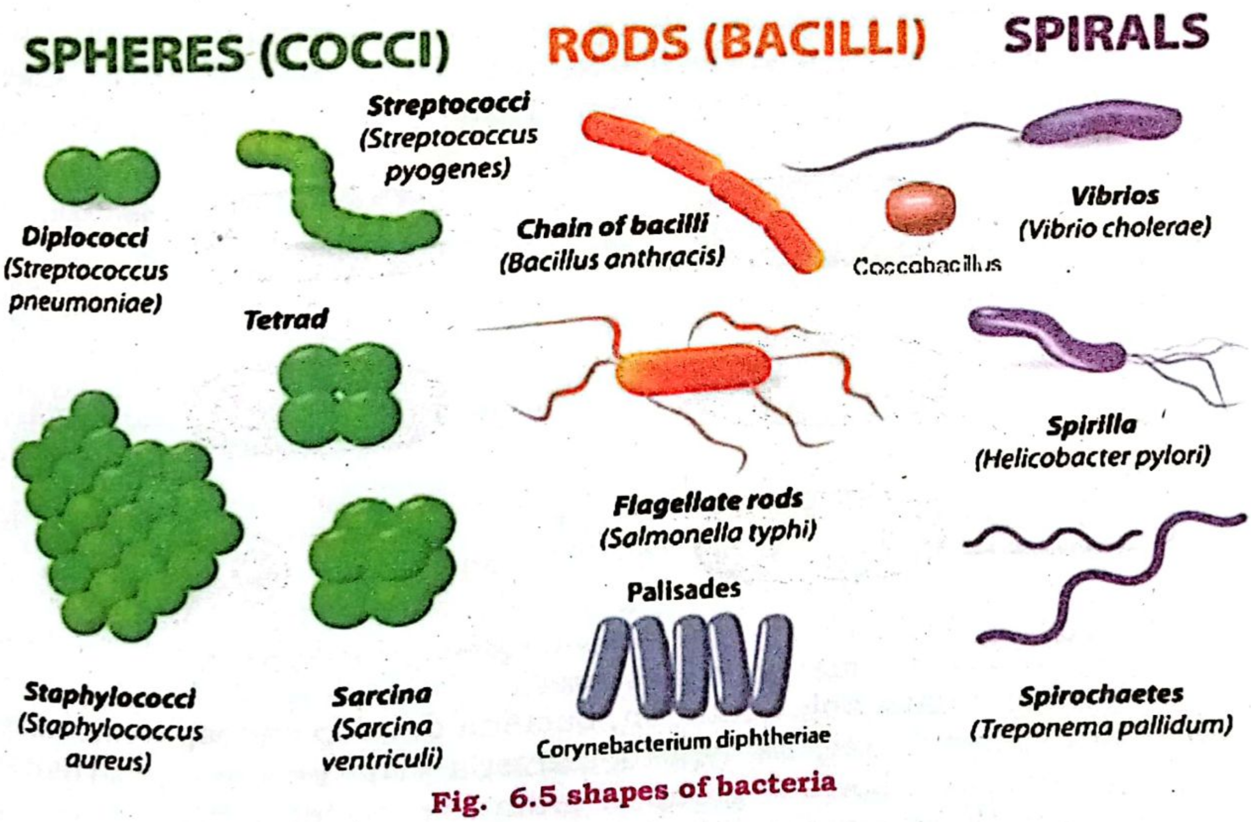


Fig. 6.5 shapes of bacteria

6.4.2. The Endospore Formation in Bacteria

Bacteria are very adaptive to the changing environment. When habitat conditions become harsh and nutrients are exhausted the development of endospore is initiated. It develops inside the bacterial cell becomes highly resistant from the environmental stresses including high temperature, ultraviolet radiations, desiccation, chemical damage, enzymatic destruction which protect bacterial genetic material. Bacteria are able to survive for a long period of time due to endospore as it is difficult to destroy.

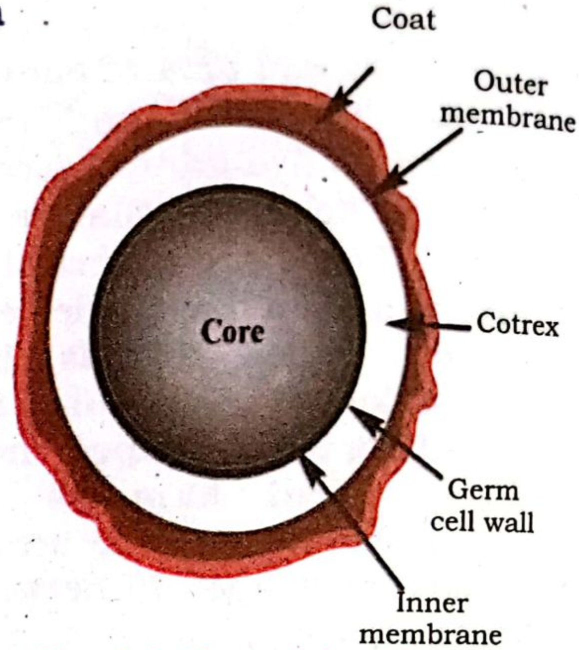


Fig. 6.6. Bacterial endospore

Endospore development

In certain bacteria like Clostridium and Bacillus, the cells tide over unfavourable conditions by forming endospores. During this process, a portion of the cytoplasm and a copy of the bacterial chromosome undergo dehydration and get surrounded by a three-layered covering. The remaining part of cytoplasm and cell wall degenerate. The resulting structure, called **endospore** can tolerate extreme environmental conditions and can remain viable for several years. When the environmental conditions become suitable, the endospore absorbs water, swells and the wall splits, releasing the cell inside. It develops a new cell wall and starts functioning as a typical bacterial cell.

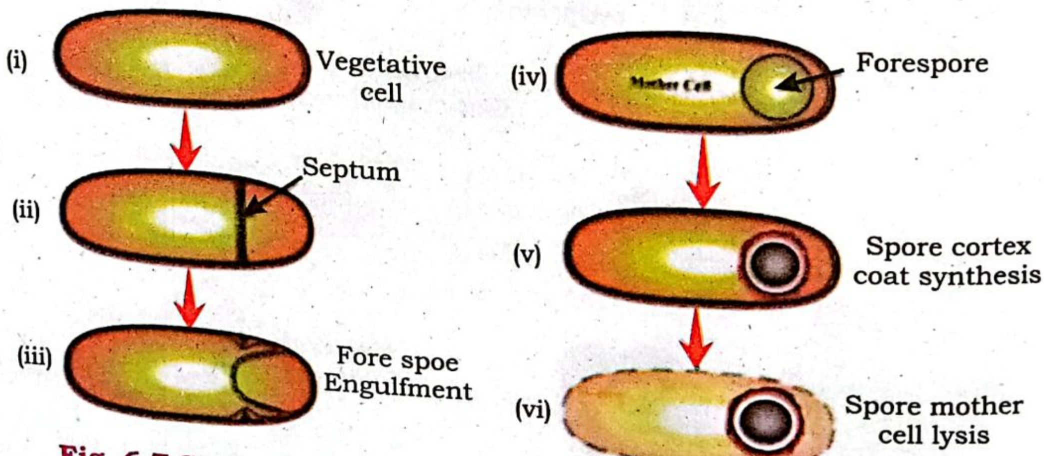


Fig. 6.7 Steps for endospore formation in bacteria

Some other survival methods of bacteria

During unfavorable condition, bacteria develop endospores, exospores and cysts, depends on the type of bacteria. The endospore formation is already discussed above. A group of gram +ve bacteria form spores, these bacteria form long tubules called filaments, which differentiate into thick walled, round structure called exospore. These structures are the part of the reproductive process and formed outside the cell wall e.g. Actinomycytes.

In other type of bacteria like azobacter species, the cyst is formed. These cyst are dormant cells with thick cell wall the cytoplasm contract. The cyst formation occur by changing cell wall. These bacterial cells become resistant to desiccation and some chemical. These cells are not same resistat to temperature like endospore.

6.4.3. Motility in bacteria

Movement in bacteria depends on various stimuli in their surroundings like magnetic field, chemicals, light, temperature etc. due to which bacteria express magnetotactic, chemotactic, phototactic, movements respectively. Bacteria moves by its flagella in particular direction towards or away from the stimulus they detect. Flagella are present in different numbers and positions over the cell body. Sometimes bacteria floats with the help of their pili that provides buoyancy to the cell body. Generally, there are three types of movement in bacteria.

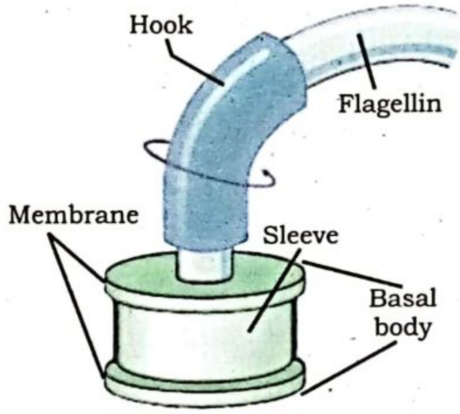
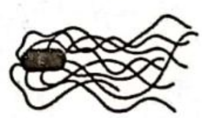


Fig. 6.8 Direction of movement of bacterial flagella

(a) Flagellar movement:

Bacterial flagella embedded with cell wall by motile and help in locomotion. Prokaryotic flagellum moves the cell by rotating from the basal body either clockwise or counter clockwise around its axis. The helical waves are generated from the base to the tip of flagellum that pushes against water and propels the bacterium.

On the basis of number of flagella bacteria are classified as:

Atrichous	bacteria without flagella	
Monotrichous	bacteria with single flagella at one pole present.	
Lophotrichous	bacteria with a tuft of flagella at one pole present	
Amphitrichous	bacteria with a tuft of flagella at each of two poles present	
Peritrichous	bacteria are surrounded by flagella	

(b) Spirochaetial movement:

The spirochaetes show several types of movements such as flexing, spinning, free swimming and creeping as they are flexible and helical bacteria lack flagella. Just within the cell envelope they have flagella like structure which are known as periplasmic flagella or axial fibrils or endo-flagella.

(c) Gliding movement:

Some bacteria such as the species of cyanobacteria (e.g. Cytophaga) and mycoplasma show gliding movement when come in contact with a solid surface. It helps to find out the substratum e.g., wood, bark, shell, etc. for anchorage and reproduction. They secrete slime with the help of which they get attached to the substratum. However, no organelles are associated with the movement.

6.4.4. Structure of Bacterial Flagellum

Bacterial flagella are long, thin (about 20 nm), whip-like appendages that move the bacteria towards nutrients and other attractants. Flagellum is made up of protein called flagellin. Flagellum has three distinct regions the hook, the filament and the basal body. The wider region at the base of the flagellum is called a hook. It is different in structure than that of the filament. Hook connects filament to the motor portion of the flagellum called a basal body. The basal body anchored in the cytoplasmic membrane and cell wall. It contains the rotating motor, which is powered by ATP and a C ring. The C ring is a proteinaceous cup-shaped structure and attached to the cytoplasmic side of the basal body and works as the rotor of the motor.

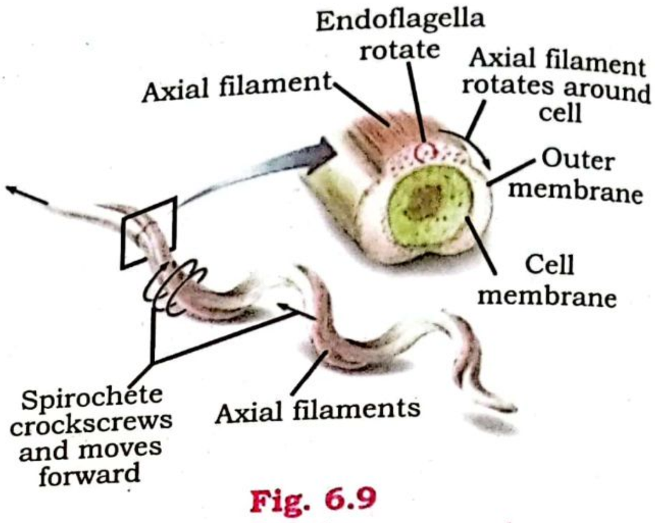


Fig. 6.9
Spirochaetial movement

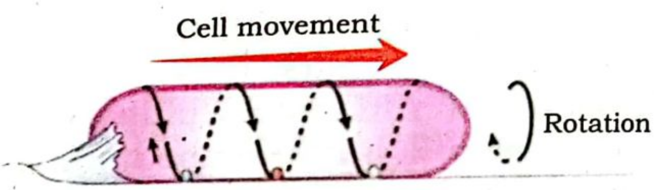


Fig. 6.10
Bacterial gliding movement

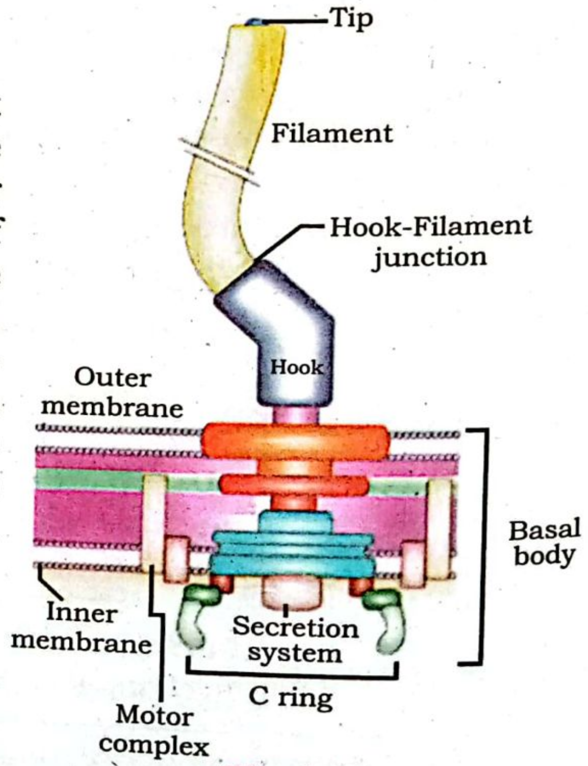


Fig. 6.11
Anatomical structure of bacterial flagella

6.4.5. GENOMIC ORGANIZATION OF BACTERIA

The term genome refers to the sum of an organism's genetic material. The bacterial genome or **nucleoid** is composed of a single molecule of chromosomal deoxyribonucleic acid (DNA) located in a region of bacterial cytoplasm visible under electron microscope. The bacterial chromosome is one long, single molecule of double stranded, helical, supercoiled DNA. In most bacteria, this DNA is circular. Bacterial nucleoid may contain as many as 3500 genes. Unlike the eukaryotic nucleus, the bacterial nucleoid has no nuclear membrane or nucleoli. The bacteria have only one copy of DNA, that is they have only one chromosome and only reproduce asexually, cell divide by amitosis.

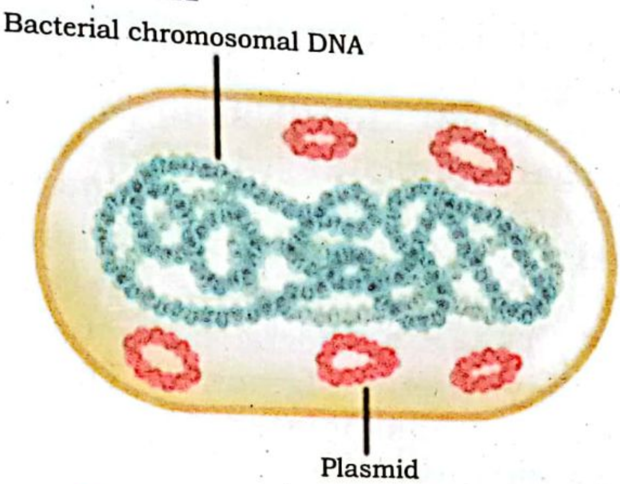
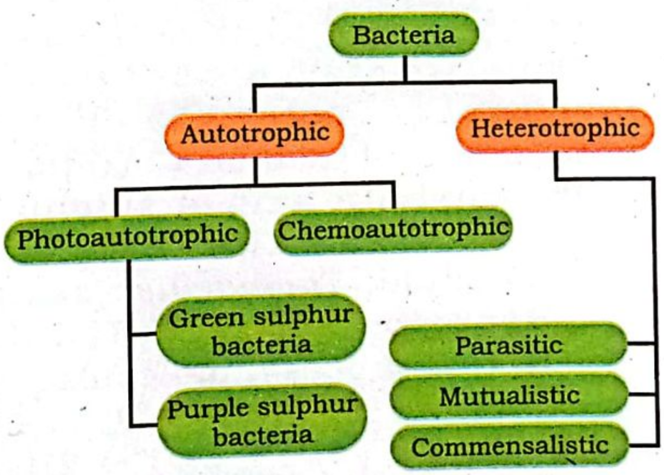


Fig. 6.12 Bacterial Chromosome

In addition to the bacterial chromosome, many bacteria often contain small non chromosomal extra circular DNA molecules called **plasmids**. They usually contain between 5 and 100 genes. Plasmids replicate independently of the host chromosome. They are not essential for bacterial growth under normal environmental conditions. The plasmid increases the immunity of bacterial cell. The bacterial plasmid may be use in rDNA technology is carrier of gene.

6.5. MODES OF NUTRITION IN BACTERIA

Bacteria require carbon and energy to synthesize their cell components by different processes. They can obtain energy and nutrients in different ways like photosynthesis, chemosynthesis, decomposing of dead organisms and wastes, establishing mutualistic and parasitic relationships. They are classified on the basis of their mode of nutrition into two types, autotrophic bacteria and heterotrophic bacteria.



1. Autotrophic bacteria

Autotrophic bacteria synthesize their own food from simple inorganic sources like CO_2. In this process, energy is obtained from either sunlight or chemically by the oxidation of some inorganic substances like iron, sulphur, nitrogen compounds, etc. Autotrophic bacteria are further divided into two types on the basis of their energy utilization.

a. Photoautotrophic Bacteria

These bacteria have bacteriochlorophyll or chlorobium as photosynthetic pigments. These pigments are present in specific vesicles associated with bacterial membrane called **chromatophores**. These bacteria use light energy as a source and hydrogen sulphide or other H^+ donor as reducing agent instead of water to make carbohydrates, therefore does not release oxygen but release sulphur as by product.

$$2H_2S + CO_2 \xrightarrow[\text{bacteriochlorophyll}]{\text{Light energy}} (CH_2O)_n + 2H_2O + 2S$$

$$H^+ \text{ donor} + CO_2 \longrightarrow (CH_2O)_2 + 2H_2O + \text{Salt}$$

b. Chemoautotrophic Bacteria

a. Chemoautotrophic bacteria prepare their food by using inorganic raw material in the absence of photosynthetic pigment.
b. In this process, chemical energy is obtained from the oxidation of certain inorganic substances such as ammonia, nitrates, ferrous ion, hydrogen sulphides, and some metallic and nonmetallic substances.
c. In this reaction, chemical bonds are broken, to release energy, which is used to drive the synthetic processes of the cell.
d. These are again divided into the following types:

i) Sulphur Bacteria (Sulphomonas)

These types of bacteria oxidise elemental sulphur or H_2S and release sulphuric acid or sulphur.

$$2S + 2H_2O + 3O_2 \rightarrow 2H_2O + 2S + \text{Energy}$$

Example: *Thiobacillus denitrificans*

ii) Hydrogen Bacteria (Hydromonas)

In this process, molecular hydrogen is oxidized into water.

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Energy}$$

$$4H_2 + CO_2 \rightarrow 2H_2O + CH_4 + \text{Energy}$$

Example: *Hydrogenomonas, Pseudomonas.*

iii) **Iron Bacteria (Ferromonas)**

They use chemical energy by oxidation of ferrous compounds into the ferric compounds.

$$4FeCO_3 + 6H_2O + O_2 \rightarrow 4Fe(OH)_3 + 4CO_2 + Energy$$

Example: *Thiobacillus, Ferrobacillus*, etc.

iv) **Methane Bacteria (Methanomonas)**

These types of bacteria get their energy from the oxidation of methane; byproducts are water and carbon dioxide.

v) **Nitrifying Bacteria (Nitrosomonas)**

Bacteria get their energy by oxidation of nitrogen compounds into nitrates.

$$2NO_2 + O_2 \rightarrow 2NO_3 + Energy$$

Example: *Nitrobacter, Nitrosomonas.*

vi) **Carbon Bacteria:**

These types of bacteria oxidize CO into CO_2.

$$2CO + O_2 \rightarrow 2CO_2 + Energy$$

Example: *Bacillus oligocarbophillous*

2. **Heterotrophic Bacteria**

Heterotrophic bacteria do not have photosynthetic pigments and are not capable of synthesizing their own food from organic or inorganic compounds. They are of three types:

a. **Saprotrophic Bacteria**

Saprotrophic bacteria obtain food by decaying matter (humus) and dead organisms. They secrete enzymes that break down complex organic compounds into simpler products which are then absorbed as nutrients, for example *Bacillus mycides, Azotobacter.*

b. **Parasitic Bacteria**

Parasitic bacteria live on and within the body of other living organisms and gets nutrition from them. During their living they harm their host and cause different diseases in both animals and plants hence they are called pathogenic bacteria, e.g., *Vibrio cholerae, Diplococcus pneumoniae*, etc.

c. **Mutualistic Bacteria**

Mutualistic bacteria live in close association with other living organisms so that they both benefit from each other so neither of them is harmed. Symbiotic bacteria fix free atmospheric nitrogen into nitrogenous compounds which are utilized by the plants, and in return, the plant gives nutrients and protection to the bacteria. For example, nitrogen fixing bacteria like *Rhizobium, Bacillus spp., Clostridium* that lives in the root nodules of leguminous plants as mutualists.

6.5.1. Differentiate between the photosynthesis mechanisms in cyanobacteria and other photosynthetic bacteria.

Photosynthesis in cyanobacteria	Photosynthesis in bacteria
These are oxygenic prokaryotes	These are non-oxygenic bacteria
Utilize H_2O as H^+ donor	Utilize H_2O or organic acids as H^+ donor
Have chlorophyll as necessary pigment	Have bacteriochlorophyll
Have only one type of photosynthetic mechanism	Have different mode of photosynthetic mechanism according to environmental condition

6.6. GROWTH AND REPRODUCTION IN BACTERIA

6.6.1. Growth in bacteria

Growth of bacterial cultures is defined as an increase in the number of bacteria in a population rather than in the size of individual cells. The growth of a bacterial population occurs in a geometric or exponential manner. Exponential describes a very rapid increase.

1. Lag Phase

The word **lag** describes a kind of slowness or delay. Immediately after providing fresh nutritive medium, the bacterial population initially remains unchanged. Although there is no apparent cell division occurring but the cells growing in volume or mass.

2. Exponential (log) Phase

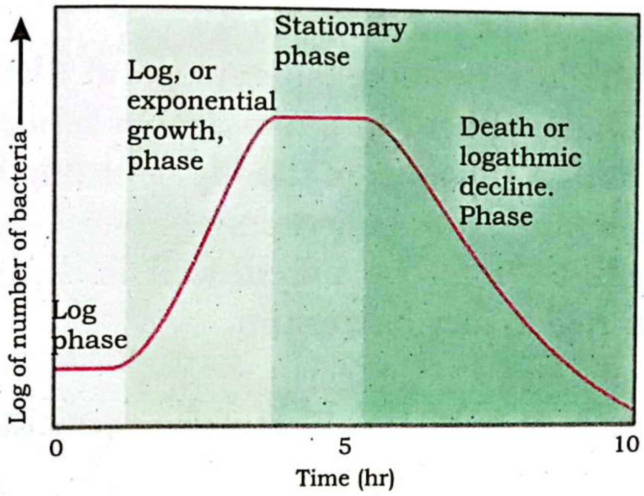
The exponential phase of growth is a pattern of balanced growth where in all the cells are dividing regularly and rapidly by binary fission. The cells divide at a constant rate depending upon the composition of the growth medium and the conditions of incubation. The growth of bacteria is very high during this phase.

3. Stationary Phase

The log phase of bacterial growth is followed by the stationary phase, in which the size of a population of bacteria remains constant, increase in bacterial population has simply stopped. In this phase rate of reproduction is equal to rate of death.

4. Death Phase

If incubation continues after the population reaches stationary phase, a death phase follows, in which the viable cell population declines. During this rate of death is higher than rate of reproduction. This phase ends at complete exhaustion of nutrients.



Graph 6.13 Growth in bacteria

6.6.2. Reproduction in Bacteria

Bacteria being prokaryotic organism reproduce by asexual methods. Sometime bacteria can perform genetic recombination. Bacterial modes of reproduction are as follows.

Asexual reproduction in bacteria

The following methods by which asexual reproduction in bacteria takes place. The methods are:

1. Binary Fission   2. Conidia   3. Budding.

1. Binary Fission

It is the most common and fastest mode of asexual reproduction in bacteria. In binary fission, single cell divides into two equal cells (Fig. 6.14). Before binary fission occurs, the cell must copy its genetic material (DNA). The double stranded DNA molecule i.e., incipient nuclei, are then distributed into two poles of the dividing cell without spindle formation, a transverse septum develops and cytoplasm is cleaved in two regions of the cell from the middle separating the two daughter cells. In many bacteria, new cell wall is synthesized. The binary fission is a rapid process and cell undergoes division at an interval of 20-30 minutes.

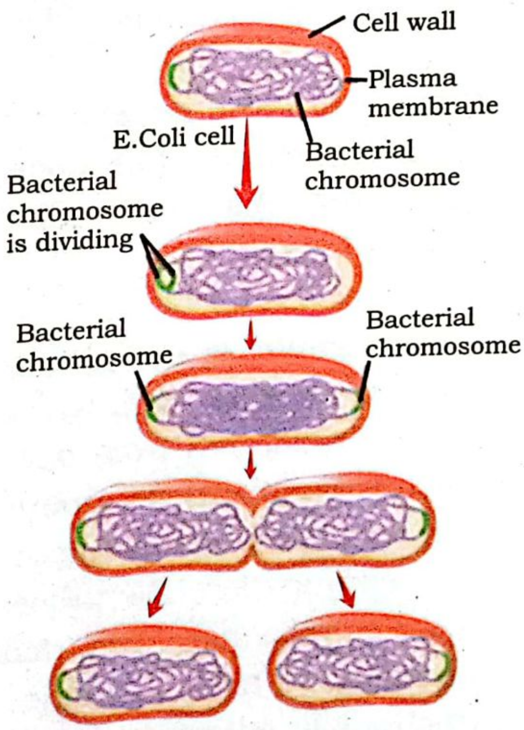


Fig. 6.14.
Binary fission in *E. coli* bacteria

2. Conidia:

Like fungi conidia formation takes place in filamentous bacteria like *Streptomyces* etc. conidia appear as small spores separated by the formation of a transverse septum at the apex of the filament (Fig 6.15). The part of this filament which bears conidia is called conidiophore. After maturity conidia detached as a fragment from the parent cell and germinates on suitable substratum to gives rise to new bacterium.

3. Budding:

Budding has been observed in some members of the Planctomycetes, Cyanobacteria etc. In budding the bacterial cell develops small swelling at one side which gradually increases in size. Simultaneously the nucleic material undergoes division, where one remains with the mother cell and other one with some cytoplasm goes to the swelling. This outgrowth is the bud, which gets separated from the mother by partition wall, e.g., *Hyphomicrobium vulgare, Rhodomicrobium vannielia,* etc.

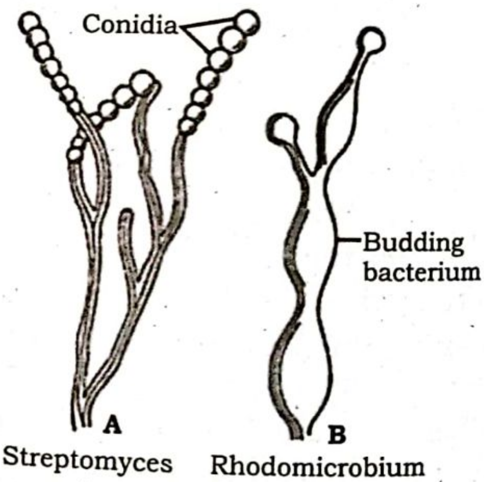


Fig. 6.15. Budding in bacteria

6.6.3. Mutation and genetic recombination in bacteria

Sexual reproduction does not take place in bacteria however genetic recombinations may take place accidently and regularly which causes mutation in bacteria.

1. Conjugation

Conjugation is the process by which one bacterium transfers genetic material to another through direct contact. During this process, DNA plasmid is transferred from one bacterium (the donor) of a mating pair into another (the recipient) via a pilus or cytoplasmic bridge.

It is a parasexual mode of reproduction in bacteria. However, in bacterial conjugation, the process involves transfer of only a portion of the genome i.e., plasmid from donor to recipient cell unlike regular sexual reproduction. Thus, genetic transfer in bacterial conjugation is unidirectionally followed by separation of the cells and further changes in the organization or recombination of the combined genetic material within the recipient cell. While new cell in not formed therefore it is not completely considered as sexual mode of reproduction.

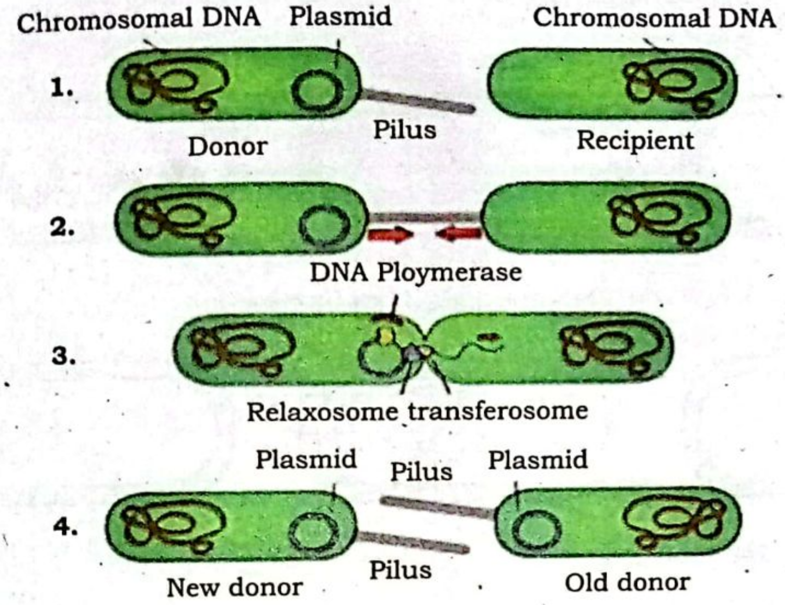


Fig. 6.16 Conjugation

2. Transformation

In transformation, a bacterium takes in DNA from its environment, often DNA that's been shed by other bacteria. In a laboratory, the DNA may be introduced by scientists. If the DNA is in the form of a circular DNA called a plasmid, it can be copied in the receiving cell and passed on to its descendants.

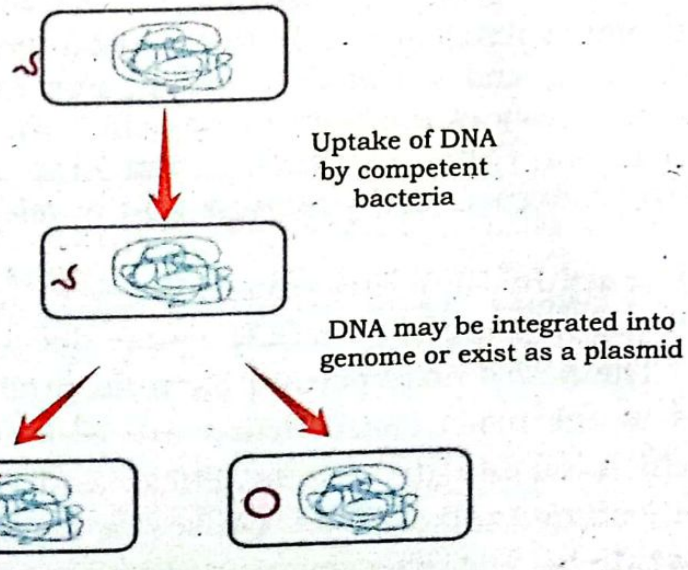


Fig. 6.17 Bacterial transformation

3. Transduction

A process in which genetic material is transferred by phage between two bacteria is called transduction.

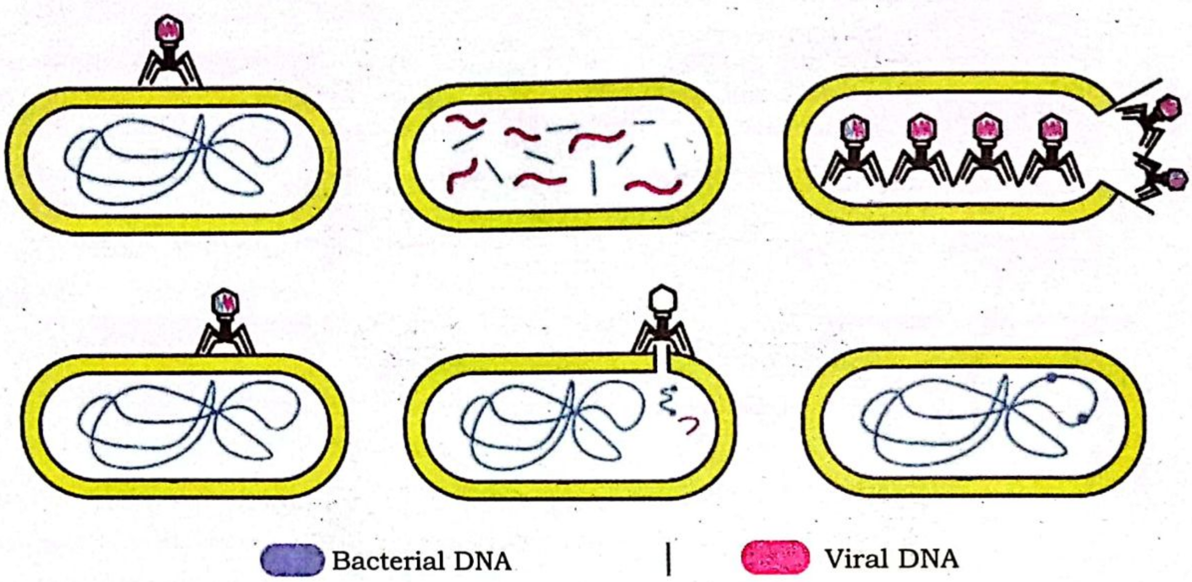


Fig. 6.18 Bacterial transduction

6.7. IMPORTANCE OF BACTERIA

Bacteria are both useful and harmful to us. Bacteria are economically important as these microorganisms are used by humans for many purposes. The beneficial uses of bacteria include the production of traditional foods such as yogurt, cheese, and vinegar. Microbes are also important in agriculture for the fertilizer production. Bacteria decompose organic matter and release minerals into the environment. *Rhizobium leguminosarum* as symbiont and perform nitrogen fixation in the roots of leguminous plants due to which plants flourish and increase productivity. Bacteria are used in genetic engineering and medical research. For example *Escherichia coli* is used for the synthesis of antibiotic amoxicillin and commercial preparation of riboflavin (vitamin B_2) and vitamin K. Bacterial plasmid is used in genetic engineering to produce useful products and develop beneficial characters in organism

Bacteria are harmful like causes diseases in animals and plants and spoil food. Some saprophytic bacteria cause decay of our food and make it unpalatable. The activities of certain bacteria produce powerful toxins such as ptomains in the food. These toxins are powerful enough to cause food poisoning which results in serious illness and even death. For example, bacterium *Clostridium botulinum* causes a fatal form of food-poisoning known as **botulism**. The diseases caused by bacteria in man and plants are shown in the table given below

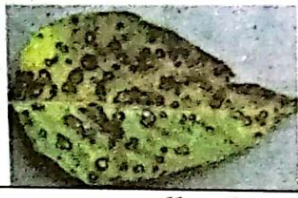
6.7.1. Bacterial diseases in Man

Table. 6.6. Bacterial diseases in man

Bacterial diseases in Man				
	Name of disease	**Cause**	**Signs and symptoms**	**Treatment and prevention**
1.	Cholera	Bacterium *Vibrio Cholera*	Diarrhea, Nausea and vomiting, Sleepiness or lethargy, Dehydration, Muscle cramps, Electrolyte imbalance, thirst, Dry skin, dry mucous membrane, and dry mouth.	Drink rehydration solution (ORS) and take antibiotics.
2.	Typhoid	bacterium *Salmonella typhi*	High grade fever and skin rash, weakness, abdominal pain, constipation, headaches.	Proper wash hands drink clean water, eat properly cooked food visit doctor if symptoms persist.
3	Tuberculosis	Bacterium *Mycobacterium tuberculosis*	cough that produces phlegm, fatigue, a fever, chills, and a loss of appetite and weight.	staying away from crowdy and congested places wearing a mask and sanitize yourself.
4.	. Pneumonia	Bacterium *Streptococcus pneumoniae*	coughing with blood and mucus, fever, sweating or chills, shortness of breath, chest pain, fatigue, loss of appetite, nausea or vomiting and headaches.	Properly wash hands, eat clean and properly cooked food, do exercise, quit smoking.

6.7.2. Bacterial diseases in Plants

Table. 6.7 Bacterial diseases in plants

		Bacterial diseases in Plants		
	Name of disease	**Cause**	**Signs and symptoms**	**Treatment and prevention**
1.	Bacteria Leaf Spots	Bacteria *Pseudomonas* and *Xanthomonas*	Necrosis, sometimes leaf spots will grow together creating large black blotches on leaves or turning leaves completely black. Shoots, buds and flowers can also become black. 	Eradication of pathogen by using pathogen-tested seeds and propagated materials and proper spray.
2.	Blights in plants by bacteria	*Erwinia amylovora,* and *Xanthomonas oryzae.*	severe yellowing, browning, spotting, withering, or dying of leaves, flowers, fruit, stems, parenchyma cells damge.  	Chemical control less effective then Biological control methods.
3	Bacterial soft rots	Bacterium *Er winia carotovora*	plant tissue becomes macerated (soft and watery).  	Proper inspection of plant seeds, control weeds, avoid harvesting under wet conditions, Avoid bruising
4.	Bacterial Wilt diseases in plants	Bacterium *Erwinia tracheiphila*	Wilt diseases caused by blocking of the vessels of host plant by masses of bacteria as a result plant wilt and dies.	Control of bacterial wilt depends on control of its insect beetle vectors. Use of insecticides.

6.8. THE BACTERIAL FLORA OF HUMANS

The human body is not sterile; we become colonized by bacteria from the moment we are born. We are covered with, and contain within our intestines, approximately one hundred trillion bacteria that form the normal flora of our bodies. This normal flora helps to prevent us becoming colonized with more dangerous bacteria, which might lead to infection.

6.8.1 The normal flora

Normal flora are the microorganisms that live on another living organism (human or animal) or inanimate object without causing disease. In a healthy animal, the internal tissues, e.g. blood, brain, muscle, etc., are normally free of microorganisms. However, the surface tissues, i.e., skin and mucous membranes, are constantly in contact with environmental organisms and become readily colonized by various microbial species. The mixture of organisms regularly found at any anatomical site is referred to as the **normal flora**. The normal flora of humans consists of a few eucaryotic fungi and protists, but bacteria are the most numerous and obvious microbial components of the normal flora.

6.8.2. Significance of the normal flora

These normal floras provide us with many benefits. They prevent colonization by pathogens by competing for attachment & nutrients. They stimulate production of antibodies. Since the normal flora behave as antigens in an animal, they induce low levels of antibodies that cross react with similar antigens on pathogens, preventing infection or invasion. In large intestine some synthesize vitamins that are absorbed as nutrients by the host (e.g., vitamin K & B12). Some bacteria produce substances that inhibit pathogenic species.

6.9. CONTROL OF HARMFUL BACTERIA

The chemical and physical methods used to control harmful bacteria.

6.9.1. Chemical methods to control harmful bacteria

Bacterial harmful activities can be controlled by certain chemicals referred as disinfectants, antiseptics, antibiotics, and antimicrobial chemicals.

1. **Sterilization** is the process of destroying all living organisms and viruses.
2. **Disinfection** is the elimination of microorganisms, but not necessarily endospores, from inanimate objects or surfaces. An ideal disinfectant or antiseptic (chemical agent) kills microorganisms in the shortest possible time without damaging the material treated.

   There are different chemical that are used as disinfectant some are as follows:

a) **Phenol:** One of the first chemicals to be used for disinfection was phenol. First used by Joseph Lister in the 1860s, it is the standard for most other antiseptics and disinfectants.

b) **Halogens:** Among the halogen antiseptics and disinfectants are chlorine and iodine.

c) **Heavy metals:** A number of heavy metals have antimicrobial ability. For example, silver is used as silver nitrate in the eyes of newborns to guard against infection by *Neisseria gonorrhea*.

d) **Soaps and detergents:** Soaps and detergents decrease the surface tension between microorganisms and surfaces, and thereby help cleanse the surface.

e) **Aldehydes:** Two aldehydes, formaldehyde and glutaraldehyde, inactivate microbial proteins by crosslinking the functional groups in the proteins.

f) **Ethylene oxide:** Sterilization can be achieved with a chemical known as ethylene oxide (ETO). This chemical denatures proteins and destroys all microorganisms, including bacterial spores.

g) **Oxidizing agents:** Oxidizing agents such as hydrogen peroxide kill microorganisms by releasing large amounts of oxygen, which contributes to the alteration of microbial enzymes.

h) **Food preservatives:** Foods can be preserved by using a number of organic acids to maintain a low microbial population. Benzoic acid, Sorbic acid etc.

3. **The use of Antibiotics**

Antibiotics are compounds that are mostly derived from biosynthesis of other microorganisms. *Streptomyces* and *Penicillium* are two organisms which have given us antibiotics. Antibiotics act in different ways to kill microorganisms like

- Antibiotics that inhibit cell wall synthesis
- Antibiotics that inhibit protein synthesis
- Antibiotics that Inhibit Nucleic Acid Synthesis or DNA Replication
- Antibiotics that Interfere with Metabolic Pathways

6.9.2. Physical methods to control harmful bacteria

Boiling: 100 °C denatures proteins and alters membranes and destroy bacteria ex. Cooking,

Dry-heat oven: 170 °C for 2 hours, denature proteins and alters membranes,

Incineration: Exposure to flame or destroy bacteria by burning.

Autoclave: Heating at very high temperature like 121 °C for 15–40 minutes at 15 psi, denature proteins and alters membranes.

Pasteurization: 72 °C for 15 seconds 138 °C for 2 seconds (UHT), Denatures proteins and alters membranes it prevents spoilage of milk, apple juice, honey, and other ingestible liquids

Refrigeration: Temperature 0 °C to 7 °C, Inhibits metabolism, Preservation of food or laboratory materials.

Freezing: Below −2 °C, stops metabolism, may kill microbes, Long-term storage of food, laboratory cultures, or medical specimens.

High-pressure processing: Exposure to pressures of 100–800 MPa, denatures proteins and can cause cell lysis, Preservation of food

Hyperbaric oxygen therapy: Inhalation of pure oxygen at a pressure of 1–3 atm, Inhibits metabolism and growth of anaerobic microbes, Treatment of certain infections (e.g., gas gangrene).

Simple desiccation: Drying, Inhibits metabolism, Dried fruits, jerky. Reduce water activity: Addition of salt or water, inhibit metabolism and can cause lysis.

Lyophilization: Rapid freezing under vacuum, inhibits metabolism and preserve food this method is used in laboratory cultures, or reagents

Ionizing radiation: Exposure to X-rays or gamma rays alters molecular structures, introduces double-strand breaks into DNA.

Membrane filtration: use of membrane filter with 0.2-μm or smaller pore size, physically removes microbes from liquid solutions. It is used in removal of bacteria from heat-sensitive solutions like vitamins, antibiotics, and media with heat-sensitive components

Nonionizing radiation: Exposure to ultraviolet light Introduces thymine dimers causes mutations in bacteria used for surface sterilization of laboratory materials, water purification

2. Write short answers of the following questions:

1. Explain the structure of bacteria in detail with labelled diagram.
2. Explain the Autotrophic mode of nutrition in bacteria.
3. Explain the photosynthesis mechanism in bacteria.
4. Explain the economic importance of bacteria.
5. Explain the bacterial diseases in Man with their signs, symptoms, treatment and prevention.
6. Explain the bacterial diseases in plants with their signs, symptoms, treatment and prevention
7. What do you mean by bacterial growth? Describe its phases.

3. Write detailed answers of the following questions:

1. What are the domains of classification? Differentiate them.
2. What are protobionts? Discuss their relationship [p with prokaryotes.
3. What are the extreme conditions Archea called?
4. Differentiate between gram-positive and gram-negative bacteria.
5. Give the structure of peptidoglycan of bacterial cell wall.
6. Differentiate between transformation and transduction in bacteria.
7. Why bacteria called recycling agent in nature?
8. How bacteria increase soil fertility? Give example.
9. How cholera and typhoid spread in human population?
10. What do we mean by normal flora of bacteria?
11. List down the physical and chemical methods to control bacteria.